Ultra-Light Door Design

Presenter: Tim Reaburn, Magna International

Recipient : Vehma International, Tim Skszek, PI

Subrecipient: FCA US LLC, Steve Logan

Subrecipient: Grupo Antolin, Rich Hager

Subrecipient: Magna Closures, Eric Kalliomaki

Project ID # LM120

Overview

Timeline

- Start Date: 2015-Dec
- End Date: 2017-Dec

Budget

Total Project Funding	$ 8,444,582
• DOE:	$ 4,222,291
• Industry	$ 4,222,291
Budget Period #1	$ 4,798,574
Budget Period #2	$ 3,646,008
Total	$ 8,444,582
Total Cost (BP1, Jan 17)	$ 2,421,275
Total Cost (thru Feb 16)	$ 2,709,704

Barriers & Technical Targets

DOE FOA guidelines included a cost threshold not to exceed $5 per pound saved and 42.5% mass reduction relative to a 2016 production door assembly, while maintaining the functionality and performance of the baseline door assembly.

Accomplishments

The Ultralight Door program realized an incremental cost of $2.59 per pound saved and 40% mass reduction, while maintaining functionality and durability and safety performance of the baseline door assembly.

Technology Partners

* Vehma International
* FCA US LLC
* Arplas USA LLC
* Magna International
* Grupo Antolin NA
* Corning Glass
* Magna Closures
* Alpine Electronics of America, Inc.
* Lindita Bushi LLC

Relevance

- **Mass Reduction:** A driver's side door mass reduction of 15.62 kg provides an estimated full vehicle mass reduction of 55kg per vehicle (31kg front, 24kg rear).
- **Architecture:** The "frame behind glass" door architecture associated with the Ultralight Door is applicable to 70% of the car and light truck vehicle market, which totaled 17.3M vehicles in 2016.
- **Fuel Reduction:** A 55kg mass reduction can enable a reduction of 0.22 liters/100km fuel consumption when combined with an appropriately downsized engine to maintain the same level of performance.
- **CO_2 Benefit:** A 0.22 liter/100 km fuel reduction provides 5.1g/km CO_2 or 8.1 g/mile CO_2 benefit.
- **Cost Effective:** The $2.59 per pound saved cost model estimate provides a cost effective means to reduce CO_2 emissions.

References:

1. Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials, Workshop, pp26, 2013, US DOE VTO
2. VTO Multi-Year Program Plan 2011 – 2015. December 2010

Resources (8 companies, 13 activities, 40^{+} persons)

Magna International	Program Mgt. Door Integration	6	Chief Engineer, PI, Lead Engineer, Mechanical Design, Controller, Compliance
Vehma Eng. & Prototype	DIW	3	Product Engineer, Mechanical Designer, CAE
	DIW Fabrication Door Integration	12	Machinists & Technicians
Magna Closures	Door Module Latch Electrification	3	Product Engineer, Mechanical Designer, Controls Engineer
FCA US LLC	Durability & Safety Validation	8	Co-PI, Mechanical Designer, Product, Safety CAE & Test Engineers
Grupo Antolin NA	Interior Trim	3	Product Engineer, CAE Engineer Mechanical Designer
Arplas USA LLC	Assembly	3	Weld Engineer and Technicians
Corning Glass	Side Glass	3	Product Engineer, Mfg. Technicians
Lindita Bushi	Life Cycle	1	LCA Specialist

Milestone Status

Milestones	Scheduled Start Date	Scheduled End Date	Actual End Date	% Complete
Project Management	2015-Dec	2017-Dec	On schedule	72%
Architectural Design	2015-Dec	2016-Jan	2016-Feb	100%
Concept Design	2016-Feb	2016-Mar	2016-Apr	100%
Final Design	2016-Apr	2016-Sep	2016-Nov	100%
Technical Cost Model	2016-Jul	2016-Sep	2016-Nov	100%
Manufacture Prototype Parts	2016-Oct	2016-Dec	2017-Apr	100%
Assemble Prototype Parts	2017-Jan	2017-Feb	2017-Jun	90%
Component- and Vehicle-level Testing	2017-Mar	2017-Sep	2017-Dec	10%

- Program is on schedule for completion in December 2017 per award agreement.
- The 12 week delay in completion of prototype parts is related to a 6 week delay in the design release and the change in the number of door assemblies from 10 to 31 prototypes (production rate of 5 doors per week).

Approach

- Selection of Door Architecture

Concept A

Key Technologies
- High Pressure Die Cast Al or Mag
- Hot Stamped Steel
- Cold and Warm Formed Al or Mg Stamping
- SMC Unidirectional CF Composite

Lightweight Materials Applied
- Outer Panel: Cold Stamped 6xxx Al
- Inner Panel/Hinge Reinforcement: Die Cast Al or Mag
- Door Beam: UHSS or Warm Formed 7xxx Al
- Structural Carrier Module: CF Composite
- Door Header: CF Composite

Concept B

Key Technologies
- Aluminum Extrusion
- Hot Stamped Steel
- Cold and Warm Formed Al or Mg Stamping
- SMC Unidirectional CF Composite

Lightweight Materials Applied
- Outer Panel: Cold Stamped 6xxx Al
- Inner Panel: Carbon Fiber Reinforced Composite
- Door Beam: UHSS or Warm Formed 7xxx Al
- Hinge Reinforcement: Aluminum Extrusion
- Door Header: CF Composite

Concept C

Key Technologies
- High Pressure Die Cast Al or Mag
- Cold and Warm Formed Al or Mg Stamping
- Aluminum Extrusion

Lightweight Materials Applied
- Outer Panel: Cold Stamped 6xxx Al
- Inner Panel: Cold Stamped 5xxx Al
- Door Beam: Warm Formed 7xxx
- Hinge Reinforcement: Die Cast Al
- Door Header: Extruded Al

Approach

- Development Process

Architectural Design 2 month duration	Development and evaluation of carbon-fiber, cast aluminum and stamped aluminum door architectures, identify key technologies and lightweight materials to achieve cost and mass project objectives.
Concept Design 2 month duration	Develop and evaluate carbon-fiber, cast aluminum and stamped aluminum door architectures, characterize cost and mass benefit opportunities.
Final Design 6 month duration	Select architecture and develop detailed design, BOM and CAE analysis to achieve a functionally equivalent drivers-side door assembly. Develop weight tracking and cost model to support 42.5% mass reduction and $5/lb cost/pound saved criteria.
Prototype & Test 12 month duration	Build tooling to manufacture prototype components, assemble doors and test using industry test protocol and standards.

Approach (continued)

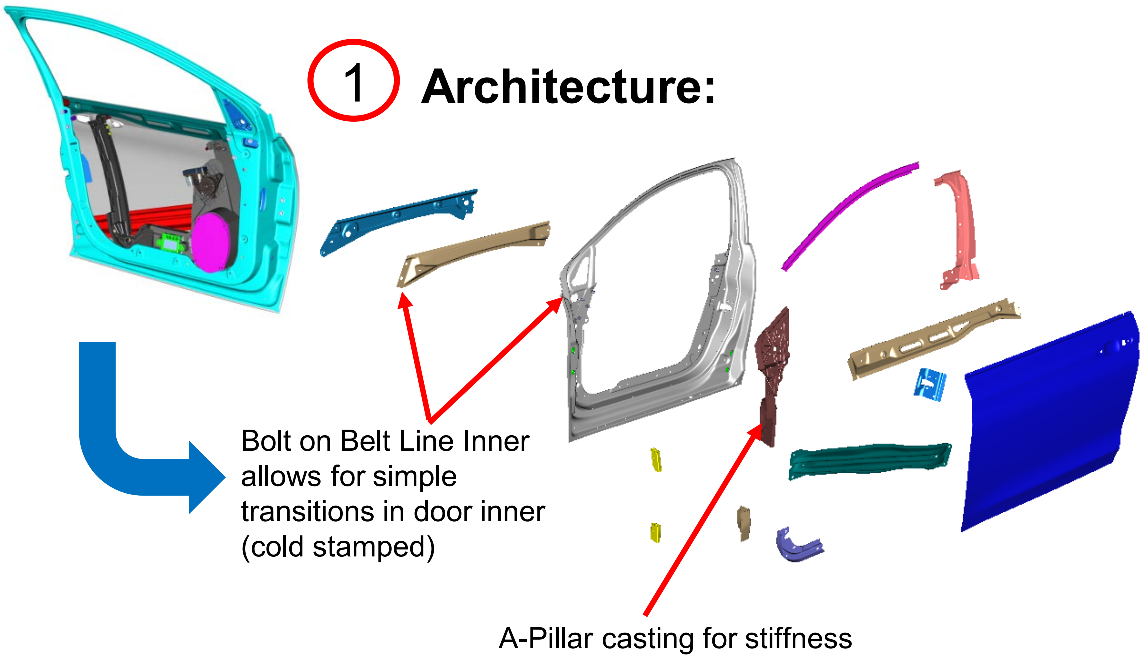
- Program Approach - Door Module and Interior Trim

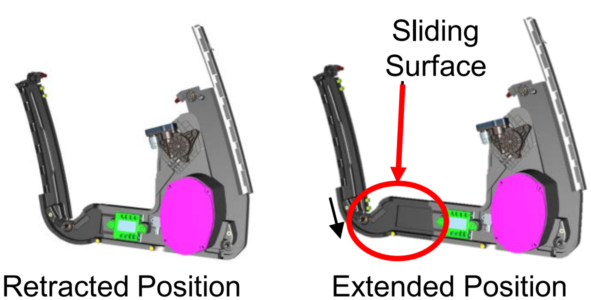
Door Module	Develop a door module which integrates glass channel guides, motors and sensors into a self-contained unit, minimizing OEM body shop assembly content. Evaluate lifting the side glass at the bottom ends instead of the bottom center to minimize mass of module and glass.
Side Glass	Investigate the potential of using chemically toughened, laminated glass to reduce glass thickness/mass while maintaining sound transmission loss characteristics.
Latch	Investigate the mass reduction potential of incorporating an electronic latch, eliminating the need for linkage and mechanical release hardware.
Wiring Harness	Investigate the use of printed flat wire harness technology and further use of serial communications (LIN and CAN bus) to minimize the number of solid conductors.
Interior Trim	Investigate part integration, use of laser joining technologies and advanced molding technologies to minimize mass and maintain functionality.

Approach

- Program Approach

1 Architecture:





2 Technologies:

- Aluminum stamped inner/outer panels
- HP aluminum casting
- Warm formed aluminum door beam
- Neodymium speaker magnet
- Aluminum extrusion and stretch bending
- Electronic SmartLatch™

+ 3 Prototype Build:

- New door module architecture
- Precision thin wall injection molding
- Arplas projection welding
- Laminated side glass with Gorilla Glass™ layer

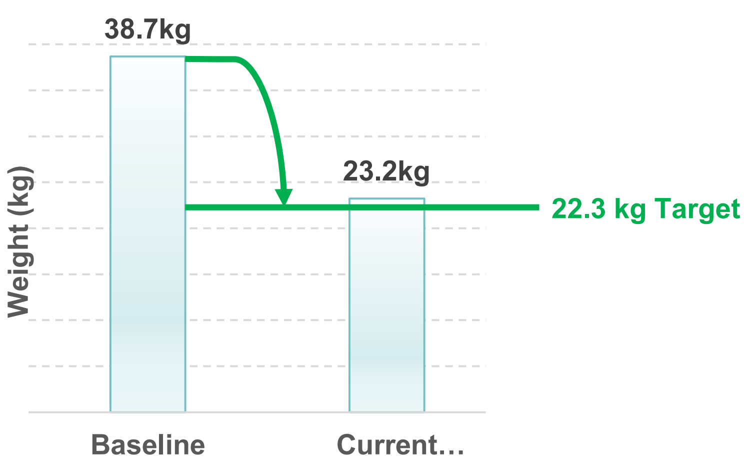
Technical Accomplishments

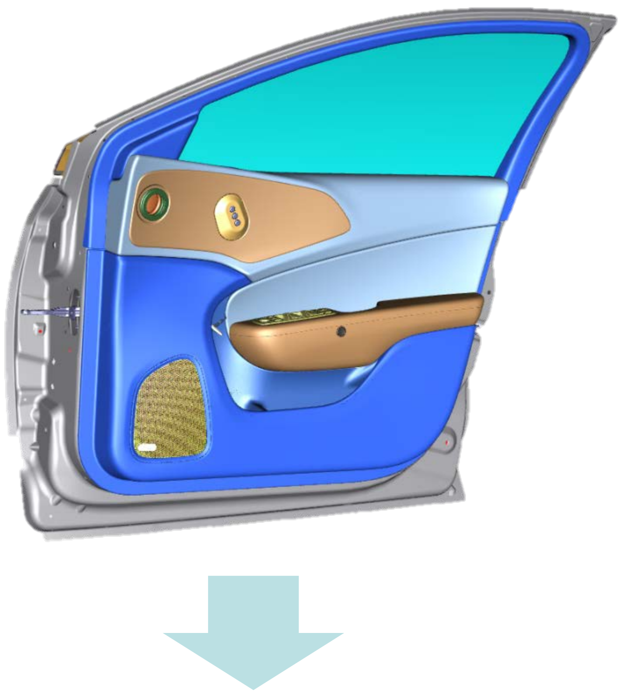
- Summary

DOE Target
42.5% Weight Reduction
$5/lb mass saved

Status
40% Weight Reduction (15.5 kg)
$2.59/lb mass saved

Current Status vs Goal





Mass reduction targets achieved by incorporating new design architecture and use of lightweight materials and advanced manufacturing technologies

Technical Accomplishments

- Mass Distribution

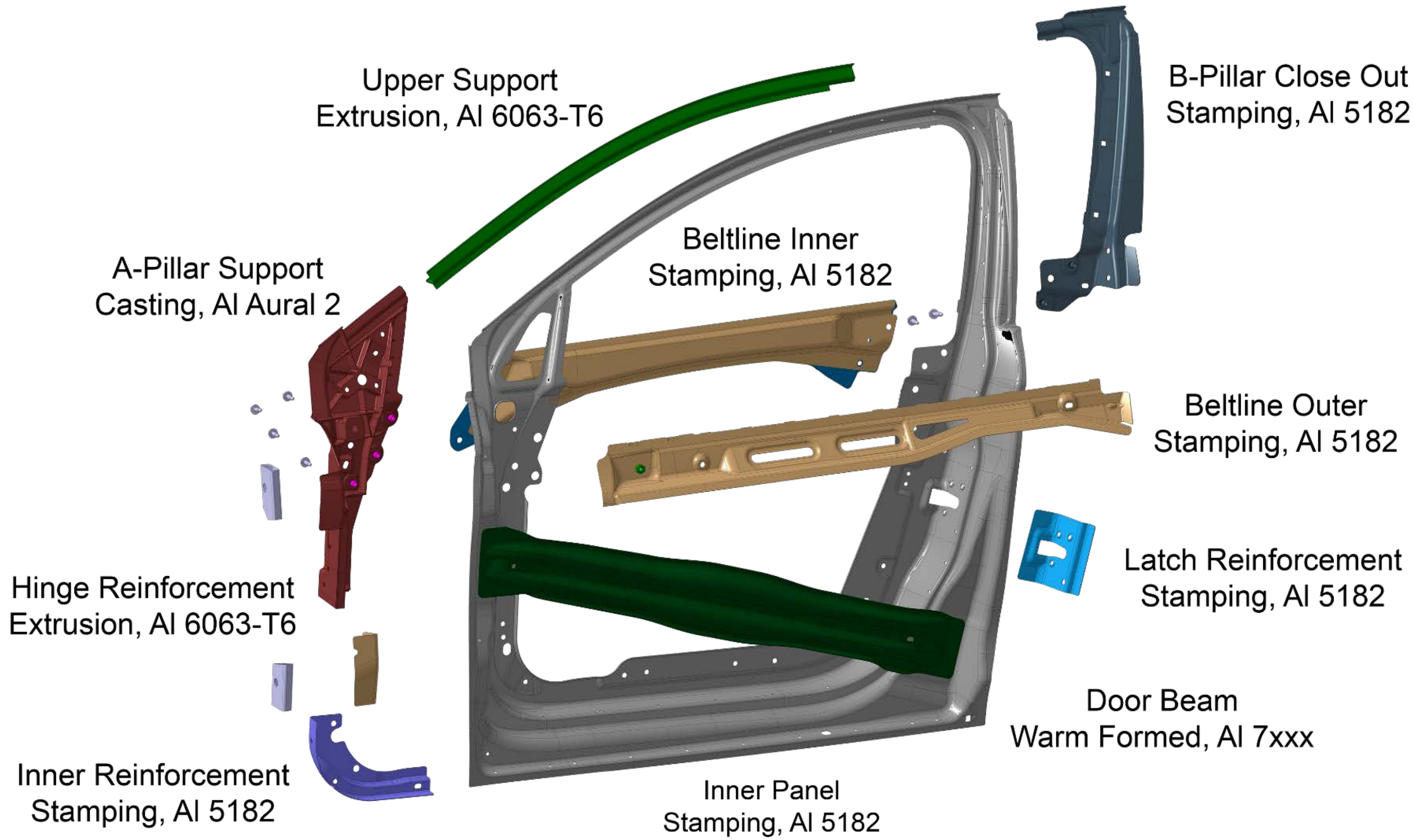
System	Baseline Mass (kg)	June 2017 Mass (kg)	% Reduction
DIW	17.42	9.69	44.4%
Interior Trim Panel and Upper Trim	4.35	2.73	37.3%
Glass Assembly	4.12	2.15	47.8%
Window System/Door Module	3.38	2.36	30.2%
Sealing System	2.18	1.84	15.3%
Mirror Assembly	1.42	1.01	28.8%
Latch Assembly	0.81	0.50	38.6%
Exterior Handle Assembly	0.65	0.19	70.3%
Hinges	0.70	0.42	40.0%
Wiring Harness	0.73	0.63	14.2%
Speaker	0.96	0.50	47.6%
Other	1.97	1.15	41.8%
Total	**38.69**	**23.17**	40.0%
Gap to Target		**0.92**	

Mass Reduction 15.52 kg

Significant mass reduction associated with DIW, Interior Trim, Glass and Door Module subsystems

Technical Accomplishments

- DIW, 8.73kg mass reduction

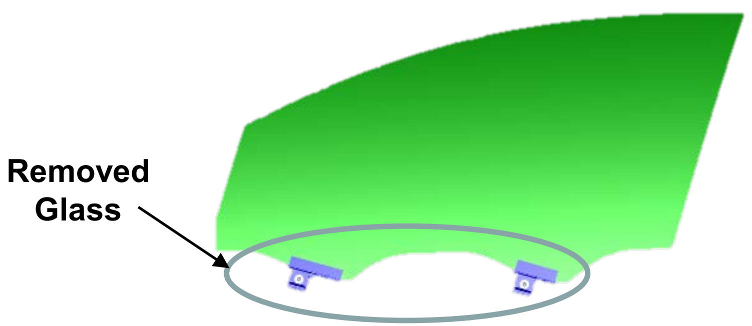


Technical Accomplishments

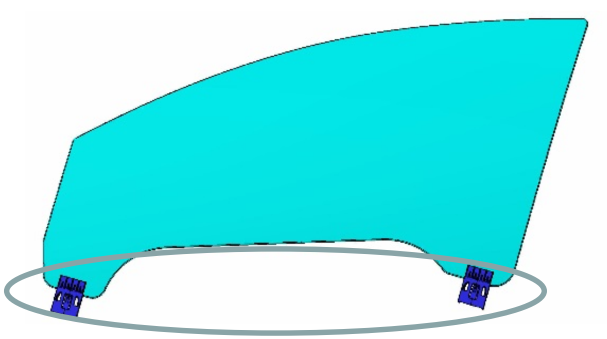
- Glass 1.97 kg mass reduction

Surface Area
(0.329 m^2 vs 0.365 m^2)

Baseline Surface Area (0.367 m^2)

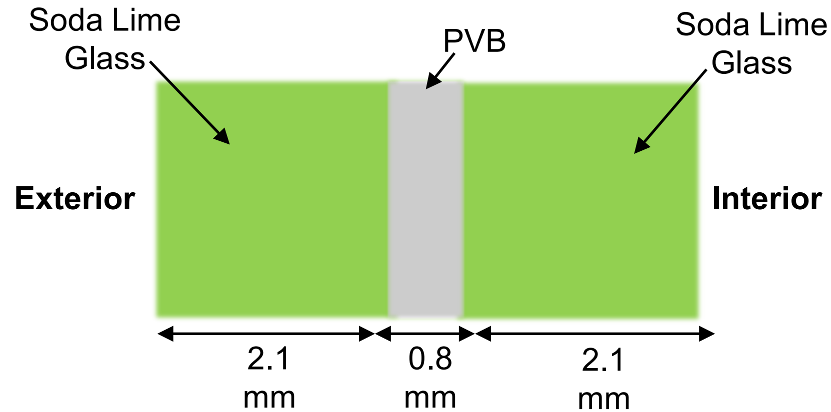


LW Door Surface Area (0.329 m^2)

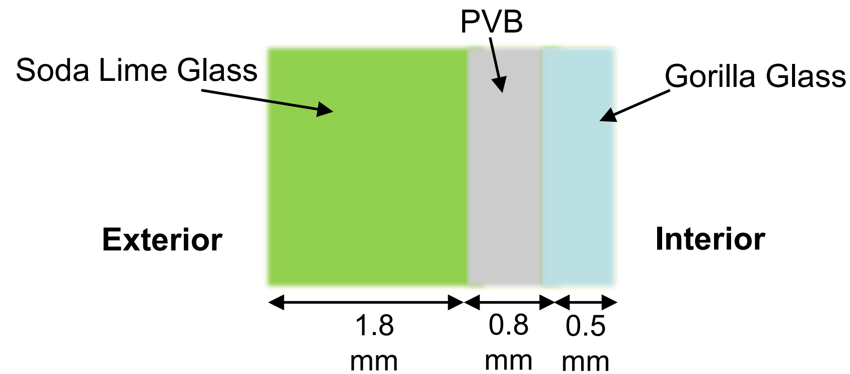


Thickness
(3.1 mm vs 5.0 mm)

Baseline Thickness



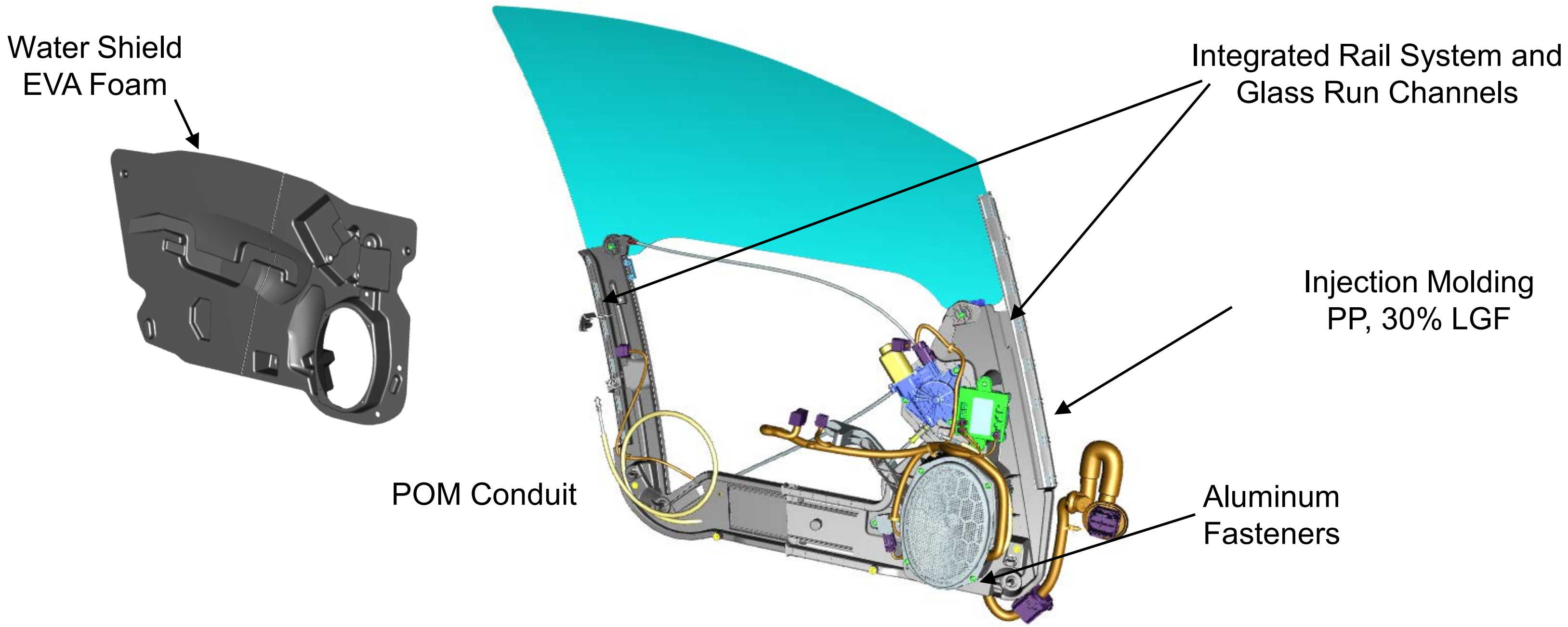
LW Door Thickness



38% reduction in thickness

Technical Accomplishments

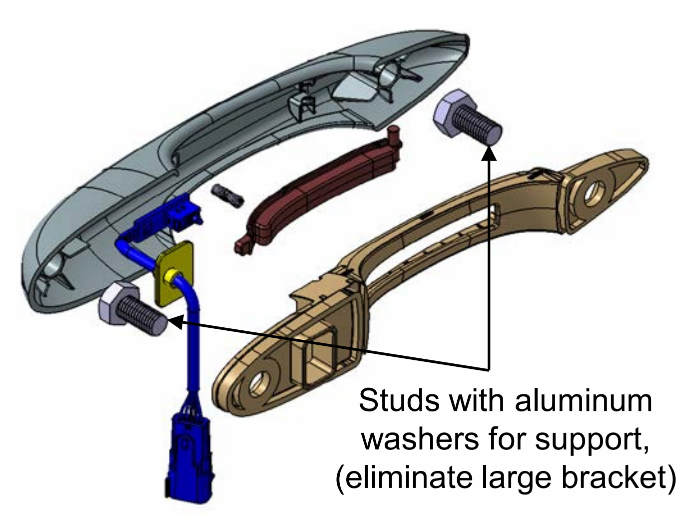
- Door Module, 1.02 kg mass reduction
  (not including glass, speaker, wire harness)

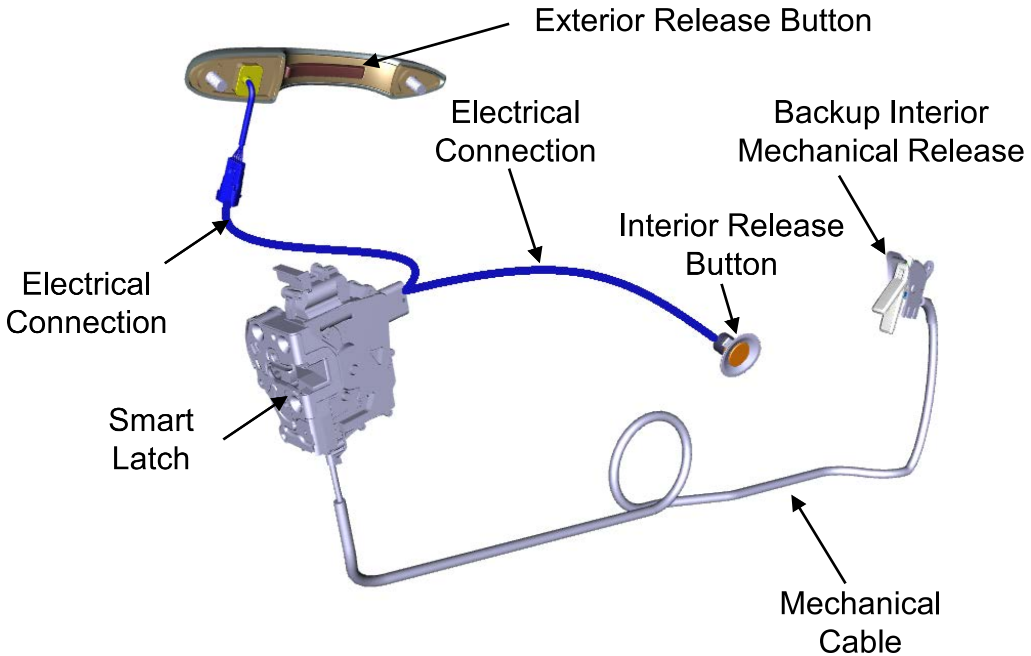


Integration of window regulator rails and glass run channels reduces components and eliminates material.

Technical Accomplishments

- Electronic Latch, 0.31kg mas reduction



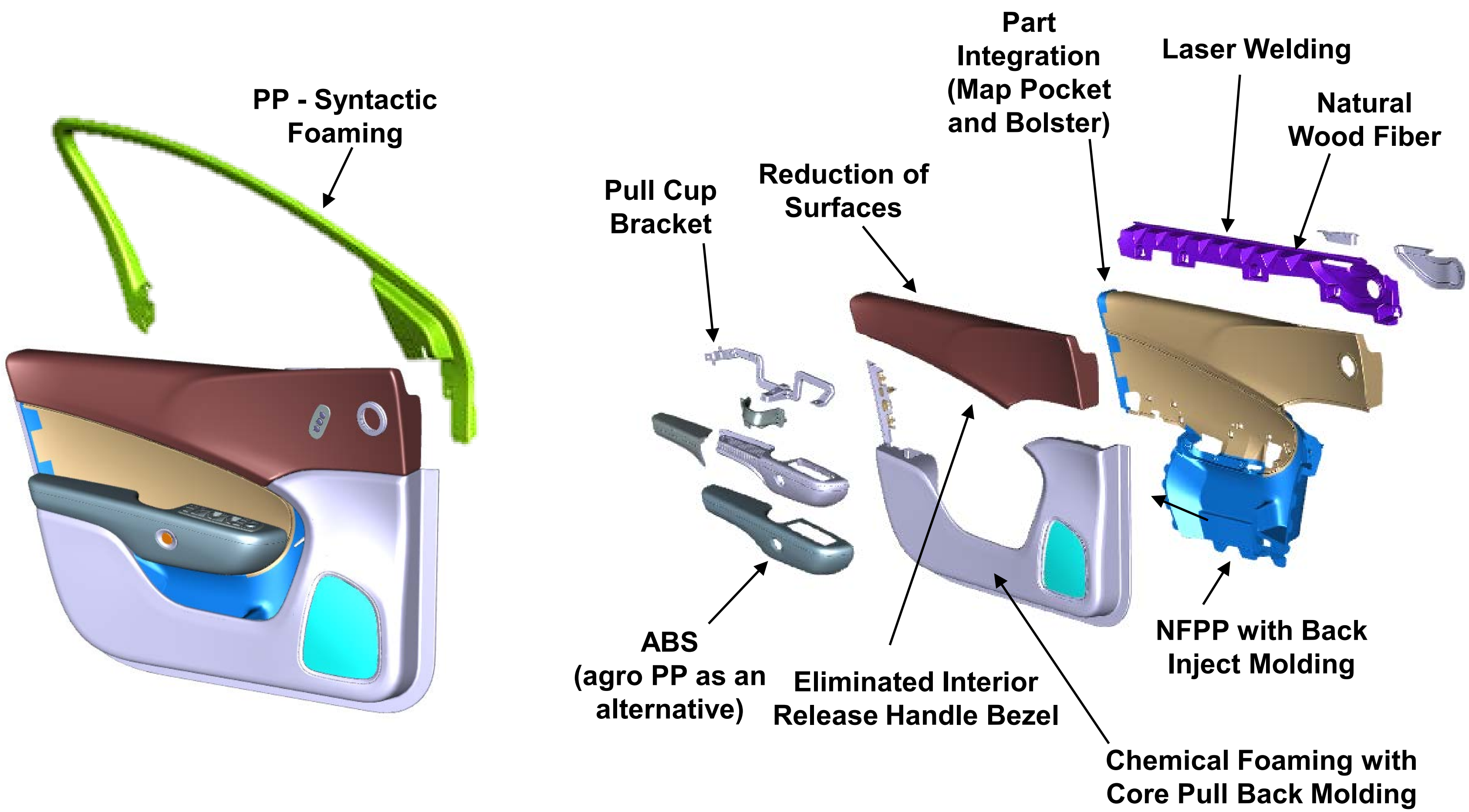


Smart latch allows door unlock and release to be electrically actuated and eliminated need for mechanical cables and rods.

Fixed handle eliminates need for support bracket and counterweight mass

Technical Accomplishments

- Interior Trim, 1.62 kg mass reduction



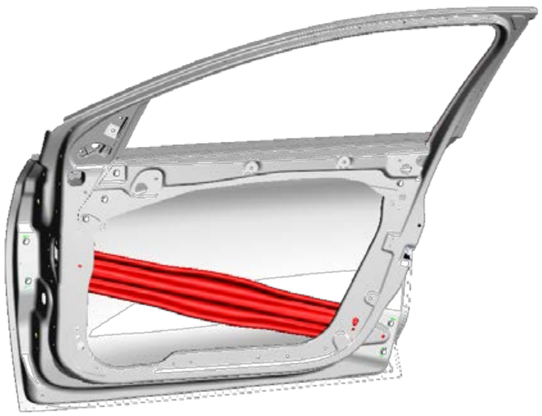
Technical Accomplishments

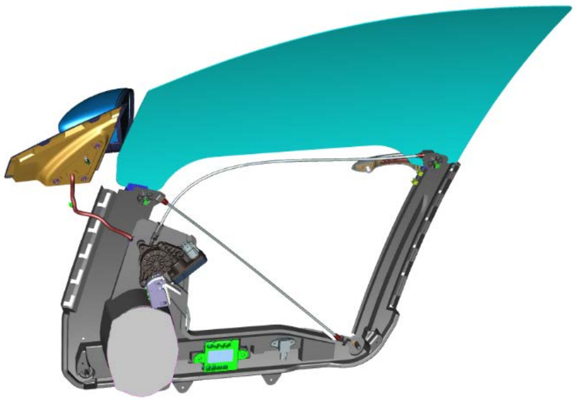
- CAE Analysis

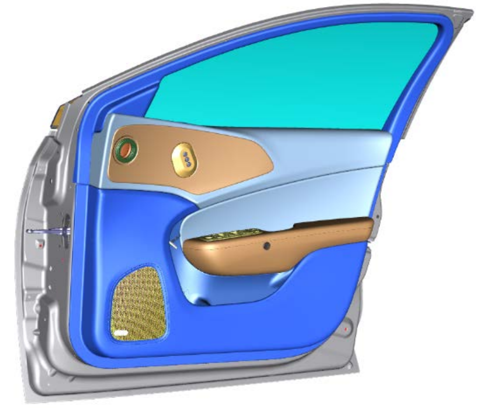
Performance Parameter	CAE Result
Structural	
Modal	
Stiffness	
Strength	
Abuse	
Safety	
Dynamic 214	
Static 214	
Efforts & Feel	
Durability	
Manufacturing Feasibility	
Cost	

Technical Accomplishments

Door Structure	Door Components	Complete Door
Minus 8.73kg	Minus 4.51kg	Minus 15.52 kg







• Relevance	Enables 5.1g CO_2/km (8.1g CO_2/mile) based on 55 kg mass reduction combined with an appropriately downsized engine
• Resources	8 companies, 13 activities, +40 persons
• Milestones	On-schedule
• Approach	Architecture selection based on mass reduction potential and cost
• Accomplishments	15.2 kg mass reduction (40%) and $2.59 cost per pound saved
• Remaining Challenge	Demonstrate equivalent NVH, corrosion, crashworthiness, durability, appearance, fit/finish, and CAE/test correlation

Reviewer Comments

Results associated with the Ultralight Door Project were not presented at the 2016 AMR

- the partners and collaborations have a solid basis for a good transition of the technologie.
- Slide 3: Recommend adding the following at the very bottom of the slide in 10 pt font (change font for bullets to 18 pt):
- References:
- 1. Light-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials, Workshop, pp26, 2013, US DOE VTO
- 2. VTO Multi-Year Program Plan 2011 – 2015. December 2010
- Slide 11: Good results!
- Slide 19: Move “Summary” slide to be next to the last slide (picture of door) in presentation per EERE presentation guidance.
- Slide 22 and 23: Reverse the order – Remaining Challenges and then Proposed Future Research per EERE presentation guidance.
- Slide 26: This is a blank slide and not necessary. Recommend deleting.

Collaboration & Coordination

Vehma Eng. & Prototype	Recipient, responsible for DIW and CAE analysis and prototype build of DIW, complete door assemblies and integration with FCA production vehicles.
Magna International	Subrecipient, responsible for door architecture and engineering, BOM, weight tracking, cost modeling door assembly/integration, side glass development and coordination of Subrecipients.
Magna Closures	Subrecipient, responsible for Door Module engineering and prototype and integration of SmartLatch.
Grupo Antolin NA	Subrecipient, responsible for engineering and prototype manufacture of interior trim & packaging of electronic latch functionality
FCA US LLC	Subrecipient, responsible for component and vehicle-level testing and speakers, as well as door functionality to facilitate commercialization opportunity.

Collaboration & Coordination

Promatek Research Centre	Subcontractor responsible for manufacture of 7xxx series warm formed door beam.
Alpine Electronics	Supplier of neodymium magnet speakers to FCA
Arplas USA LLC	Subcontractor responsible for DIW subassembly using projection welding process equipment.
Corning Glass	Subcontractor responsible for the manufacture of Gorilla Glass test panels and laminated prototype moveable glass.
Lindita Bushi LLC	Subcontractor responsible for conducting Life Cycle Analysis, documenting environmental benefit.

Remaining Challenges

Mass Reduction	Identification of cost effective materials and technologies to realize remaining 0.92kg mass reduction to achieve 42.5% mass reduction goal.
NVH	Demonstration that full vehicle NVH performance is equivalent to baseline vehicle.
Reporting	Validation of CAE & component- and vehicle-level safety and durability tests.

Proposed Future Research

- Door and Vehicle Testing

Corrosion
Full Vehicle

Safety
20 mph side pole
38 mph side deformation
31 mph IIHS side Impact
20 mph side pole, 5^{th} percentile
40 mph IIHS, 25% small overlap
FMVSS 214 static

Customer Satisfaction
NVH
Overall fit/finish, appearance, functionality, etc.

Structural & Durability
Hardware Slam
Dynamic Over Check
Sag-Set
Anti-theft
Static Over Check
Window Cycle
Water Test
Denting and Oil Can

- Comparative Life Cycle Analysis

Standards
ISO 14040/44
CSA Group 2014 LCA Guidance Document for Auto Parts

Summary

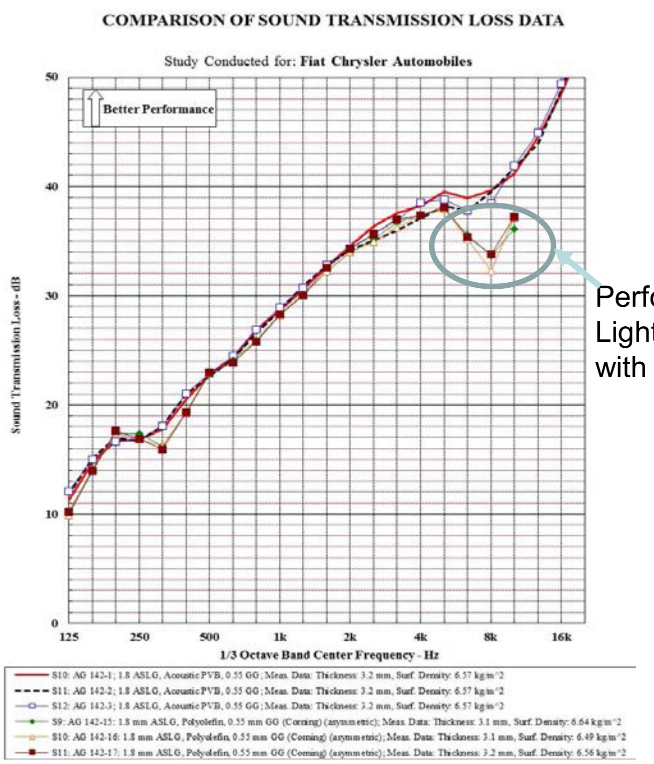
 

Item	Baseline Door	Ultralight Door
Total Mass	38.69 kg	23.17 kg
Performance	5-star	5 star (equivalent)
DIW	Steel-intensive	Aluminum-intensive
Glass	Laminated soda lime	Laminated Gorilla glass
Latch	Mechanical	Electronic SmartLatch
Door Module	Conventional	Integrated glass channels
Door Beam	Boron Steel	7xxx Aluminum
Interface	CAN-bus	LIN- and CAN-bus
Incremental Cost	Reference	Modest Increase, +$2.59/lb saved

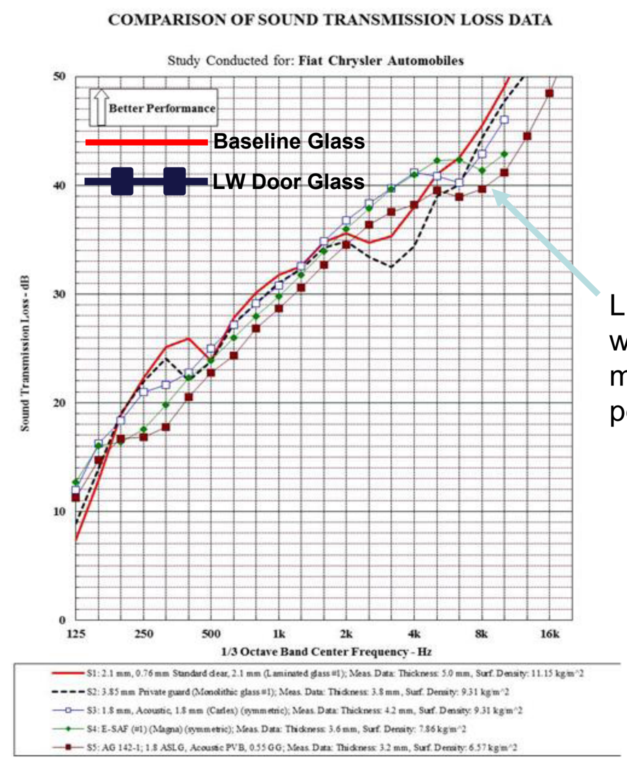
Technical Back-up

- Acoustic Glass Testing

1.8mm Soda Lime, Acoustic PVB and 0.55mm Gorilla Glass laminate selected due to combination of performance and weight savings



Performance Drop of Light Weight Glass with Polyolefin Layer



Light Weight Glass with PVB Layer maintains similar performance

Technical Back-up

- DIW Assembly Sequence